EFFICIENCY OF HEAT TRANSMISSION IN A VACUUM EVAPORATOR

BY

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ARMOUR INSTITUTE OF TECHNOLOGY

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Efficiency of heat
 transmission in a vacuum

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EFFICIENCY OF HEAT TRANSMISSION IN A VACUUM EVAPORATOR.

A THESIS

PRESENTED BY

TOLY AGAZIM

AND

JAMES G. SHAKMAN

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IN

CHEMICAL ENGINEERING

HAVING COMPLETED THE PRESCRIBED COURSE OF STUDIES

IN

CHEMICAL ENGINEERING.

APPROVED H. McCormack
Prof. of Chem. Eng.
H M Raymond

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Introduction.

Description of apparatus.

Method of procedure.

1 June, '14

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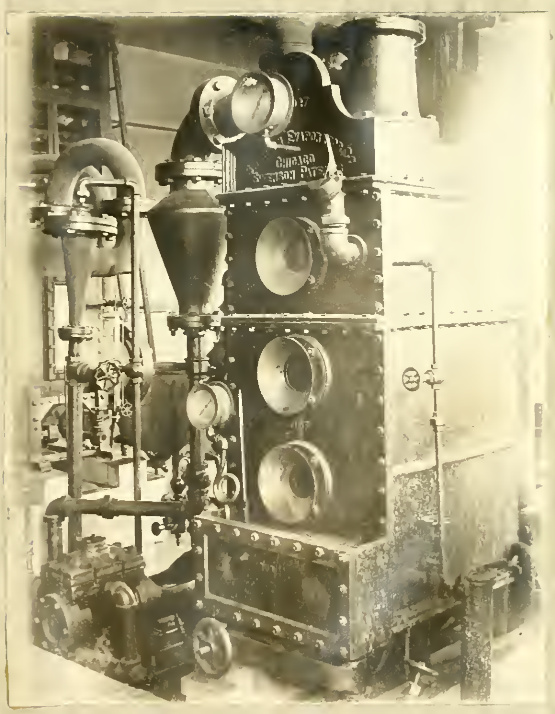
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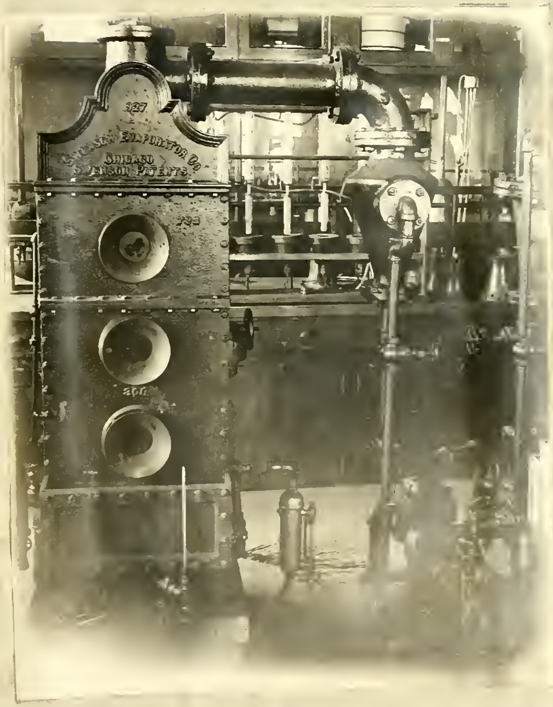
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SWENSON EVAPORATOR CO
CHICAGO
SWENSON PATENTS
793

Efficiency of Heat Transmission
in a
Vacuum Evaporator.

Evaporation plays an important part in a large number of chemical industries. It is effected by the use of various forms of apparatus, amongst the most efficient of which is that type known as the vacuum, or reduced pressure, evaporator.

The most common source of heat for use in evaporators is steam, the energy of which is transmitted to the liquid to be evaporated through metallic surfaces of some kind. Hence, it is desirable to know the effect produced on the ecomomy of evaporation by the various metals used in practice. In the following pages, we will show the behavior of the metals, copper, lead, steel, tin, and aluminum, in regard to their properties of conducting heat. Since impurities in the metals affect these properties to marked degrees, it is necessary to obtain an exact analysis of each metal used, in order that the data gathered may have comparative

value. For this reason, the metals used were analyzed, and the methods used are herein incorporated.

The evaporator used was designed by the Swenson Evaporator Company, for experimental purposes. The general outline and dimensions of the apparatus are shown in detail in the accompanying plates and drawings. The walls of the evaporator were of half inch, cast iron plate, bolted with three-eighths inch bolts. The metals used in the tests were in tube form. Thirty-two tubes fitted into holes in walls in the steam chests, and were held steam tight by means of rubber gaskets and cast iron tube plates. The tubes opened at each end into steam chests. In the entering steam chest, a guage and thermometer were inserted, in order to measure the pressure and actual temperature of the entering steam. The exhaust temperature was read from a thermometer placed in the exhaust pipe. The quality of the entering steam was determined by means of a Carpenter separating calorimeter, connected into the steam line near admission. A baffle-plate was bolted in

proper position in the dome of the evaporator, in order to prevent entrainment of water with the vapors.The vapors are taken from the evaporator through a five inch cast iron plate, which led them to a jet condenser of the parallel current, standard low vacuum type. The water from the condenser was exhausted by a direct acting steam pump. The pump was manufactured by The American Pump Company, under the following specifications:

Diameter of steam cylinder -	4 inches.
Diameter of water cylinder -	3 inches.
Diameter of piston rod-	7/8 inch.
Length of stroke -	6 inches.

The steam pressure gauge was manufactured by the Ashcroft Manufacturing Company. It was calibrated with a Crosby gauge tester, and from the data obtained, the calibration curve was plotted. By means of this curve, the gauge readings were corrected. The vacuum gauge, made by the Schaffer and Budenberg Company, was calibrated against a mercury column. A calibration curve was plotted, from which the readings were corrected. The thermometers used were compared to ~~a~~ standard thermometer.

Platform scales, used to weigh the water evaporated and the steam condensed, were checked with standard weights.

After all the instruments and metal tubes were properly set, the apparatus was inspected for steam leaks, and if none were found, the evaporator was ready for the test. If a leak appeared, it was remedied. All runs were made of two hours duration, and were made under as nearly constant conditions as possible. Throughout the experiment, steam was admitted at a pressure of ten pounds. The vacuum was varied, some tests being made at eighteen inches others at twenty. Readings were taken every five minutes during the two hours of a run, of the pressure gauge, of the vacuum gauge, of the temperature of the incoming steam, and of the temperature of the condensed steam.

In starting the run the evaporator was filled with water to a point above the upper tube level, and the conditions under which the test was to be made, were reached and maintained for a time long enough to ensure constancy. The vacuum was then broken, and the level of

the water adjusted to a definite mark, just up to the top of the tube level. It has been determined that the most economic and rapid evaporation takes place when the liquid just covers the tubes; hence, this level was maintained, approximately, throughout the run.

After adjustment of the level of the water, upon breaking the vacuum, the conditions of the test were again attained, with the least possible evaporation. As soon as these were reached, the required readings were taken, these constituting the first of the run. Water from a weighed tank, at a known temperature, was added to the evaporator at frequent intervals, in order to replace that which had evaporated. The steam exhausted into a trap (Crane Company #1), in which complete condensation took place. The condensate was collected under weighed amounts of cold water.

Data for a complete run included not only both gauge readings, and both temperature readings, but also the barometer, the weight and temperature of the water added to the evaporator, and the weight of the condensed steam. When the two hours of a run ended, the

vacuum pump and steam supply was cut off, the vacuum was broken, and the water level adjusted to the mark. It was found that, by careful manipulation, little water had to be drawn off for correct level adjustment. If the amount drawn off exceeded two pounds, the heat absorbed by it was calculated and added to that transferred during the run. For amounts under two pounds, the error introduced by not considering the heat content of the water withdrawn, was negligible. The level was carefully watched, so that it was unnecessary at the end of a test to add water to reach the proper mark.

Methods of Analysis.

Aluminum tubes.

Alkalies:

Two gram samples are dissolved in 30 cc of dilute hydrochloric acid. Ammonia in slight excess is added; the solution is boiled until barely alkaline, and filtered. The residue is dissolved in a minimum quantity of hydrchloric acid, and re-precipitated with ammonia as above. After filtration, the filtrate is added to the first, and the combined filtrates tested for aluminum. The solution evaporated is freed from ammonia salts at incipient redness. The residue is taken up in water and filtered into a platinum dish. The solution is evaporated, the residue dried and weighed, and reported as alkalies.

Silicon:

Two gram samples are dissolved in30 cc of sulphuric acid, in casseroles. The solution is evaporated to dryness and baked on the hot plate. To the residue, 30 cc of hydrochloric acid (1:1) is added; the solution is boiled and filtered. The residue is washed, dried, ignited, and weighed in platinum. Several drops

of sulphuric acid and 5 cc of hydrofluoric acid are added. The acids are evaporated and the residue is ignited and weighed. The loss in weight is the weight of silica present in the sample. From this silicon is calculated.

Iron:

Two grams of the sample are treated with 40 cc of 50 % caustic potash on the waterbath. The insoluable material is filtered off, washed, and dissolved in hydrochloric acid. This solution contains the iron present in the sample. It is titrated with fiftieth normal potassium permanganate solution by the stannous chloride method, using guard solution. Iron is reported as such.

Aluminum:

One quarter gram of sample is dissolved in hydrochloric acid. Excess ammonia is added and the solution boiled to slight alkalinity. The precipitate is filtered, washed and redissolved in a minimum amount of hydrochloric acid. Ammonia is again added and the solution boiled to traces of the alkali. The precipitate is filtered, washed, dried, ignited, and weighed.

This weight is recorded as combined iron and aluminum oxides. From this the percentage of iron, previously determined, is subtracted and from the remainder, aluminum is calculated.

Steel Tubes.

The common impurities, namely, sulphur, phosphorous, manganese, carbon, and silicon are determined by methods described in the bulletin of the Government Bureau of Standards. Circular of the Bureau number 14.

No methods of analysis appear for the copper, tin and lead tubes. We have taken the results obtained by other workers for these metals.

Data for the tubes.

Metal	Analysis	Measurements Inside diameter.	 Thick. of wall.
Copper	Cu - 99.92 % No impurities found.	.63 in.	.06 in.
Lead	Sb - 9.6 % Pb -90.2 %	.45 in.	.15 in.
Tin	Sn -99.6 % Sb - .4 %	.48 in.	.125 in.
Aluminum	Al -97.9 % Fe - 1.6 % Na - 1.1 % Si - .28 %	.6 in.	.075 in.
Steel	Si - .084% Mn - .417% C - .42 % P - .032% S - .018%	.5 in.	.125 in.

Length of tubes in contact with water - 24.5 in.

Tube	Area of tube	Perimeter of tube.	Surface Total	Total Area
Copper	.312 sq.in.	1.98 in.	10.8 sq.ft.	.0694 sq.ft
Lead	.159	1.415	7.82	.0354
Tin	.181	1.509	8.22	.0402
Aluminum	.283	1.886	10.26	.0630
Steel	.1962	1.571	8.56	.0436

MECHANICAL ENGINEERING LABORATORY

ARMOUR INSTITUTE OF TECHNOLOGY

Date..................

CALIBRATION OF VACUUM GAUGE.

By comparison with mercury column.

Maker and number of gauge ...... Schaffer and Budenburg.

Observer......................

Number	MERCURY COLUMN				GAUGE READING		Error
	INCHES			Pounds	Inches Mercury	Pounds	
	Up	Down	Mean				
		20			20.2		
		19			19,3		
		18			18.4		
		17			17.3		
		16			16.3		
		15			15.5		
		10			10.6		
		7			7.5		
		3			4.0		
		0			0		

A calibration curve is plotted for the gauge, from which the readings are corrected.

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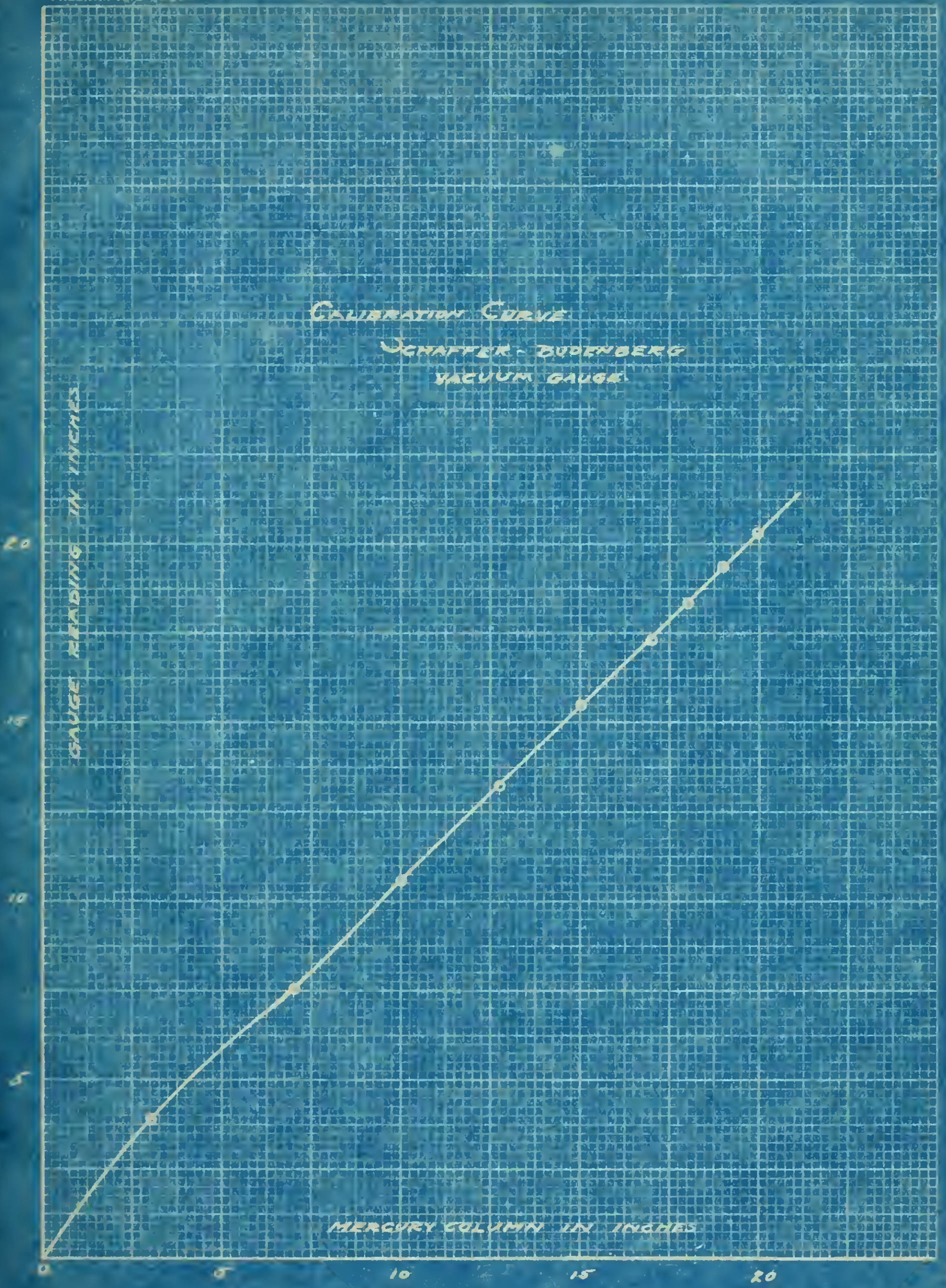


CALIBRATION CURVE
SCHAFFER - BUDENBERG
VACUUM GAUGE

MECHANICAL ENGINEERING LABORATORY

ARMOUR INSTITUTE OF TECHNOLOGY

Date

CALIBRATION OF PRESSURE GAUGE.

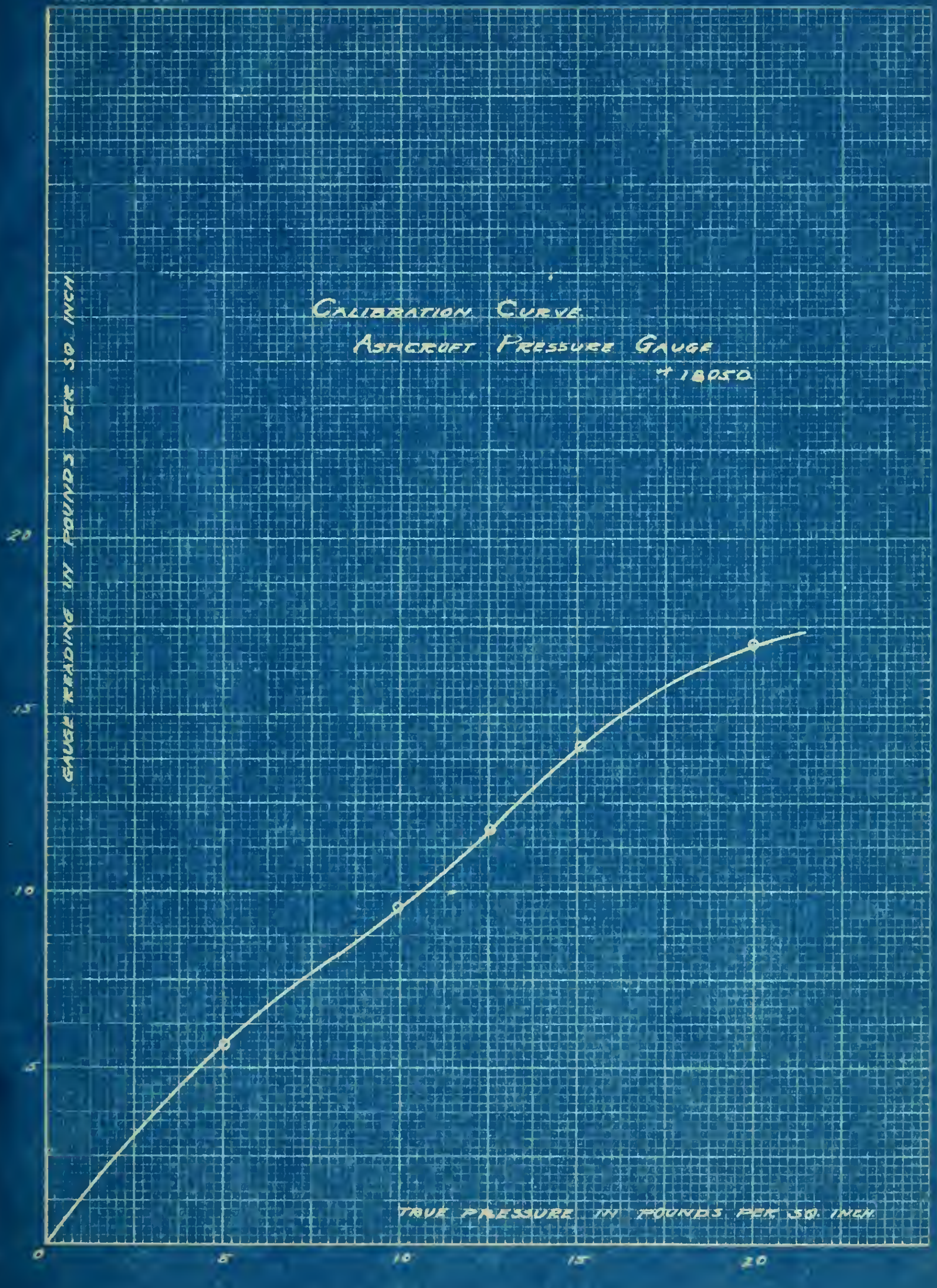
By comparison with Square Inch Gauge Tester.

Maker and number of gauge Ashcroft Company. 18050.

Observer

NUMBER	READING GAUGE TESTER POUNDS	GAUGE READING IN POUNDS						ERROR %	
		BEFORE ADJUSTMENT			AFTER ADJUSTMENT			BEFORE ADJUSTMENT	AFTER ADJUSTMENT
		UP	DOWN	MEAN	UP	DOWN	MEAN		
1	0	0	0	0					
2	5	5.7	5.5	5.6					
3	10	9.7	9.5	9.6					
4	15	15.0	14.5	14.75					
5	20	17.0	17.0	17.0					
6	30	28.0	28.0	28.0					

No adjustment was made to the gauge. A calibration curve was plotted, and readings corrected from it.



CALIBRATION CURVE
ASHCROFT PRESSURE GAUGE
#18050.

Formulae:

Heat lost by steam -

(I) $$W(xr+t_1-t_2)$$

W = weght of steam condensed.
x= quality of steam.
r = latent heat of steam.
t_1= temperature of entering steam.
t_2= temperature of exhaust steam.

###

Heat transferred to water -

(2) $$w[r_1+t_3-t_4]$$

w = weight of water evaporated.
r_1= latent heat of steam.
t_3= temperature of boiling liquid.
t_4= temperature of water atentrance to evaporator.

Quality of steam -

(3) $$x = \frac{W}{W+w}$$

x = quality of steam.
w = weight of water in steam.
W = weight of steam.

Quality of steam, corrected -

(4) $$X_c = \frac{xr+q-q_c}{r_c}$$

X_c = quality corrected.

Capacity of evaporation -

(5($$C = \frac{w}{SxW(xr+t_1-t_2)}$$

C = water evaporated per sqare foot per B.T.U.
S = total heating surface.

Velocity of steam thru tubes.-

$$(6) \qquad V = \frac{x.W.s}{A.T}$$

V = velocity in feet per minute.
s = specific volume of steam.
A = total area of steam passages.
T = time in minutes.

Mean temperature difference -

$$(7) \qquad d' = t_1 - \frac{t_3 + t_4}{2}$$

d' = mean temperature difference.

Coefficient of heat transference -

$$(8) \qquad K = \frac{60(w[r_1+t_3-t_4])}{T.S.d'.V.d}$$

K = coefficient of heat transference.
T = time in hours.
d = density of steam.

The foregoing formulates the theory upon which the results have been calculated.

Data
and
Calculations
for the
Copper Tubes.

Run One.

Time	Vacuum	Steam Pressure	Temperature of Steam Inlet	Exhaust
11:31	18	10	112° C.	85° C
:36	20	10	112.5	86
:41	19	10	112.7	87.5
:46	19.5	11	111.5	87
:51	20	10	112	85.8
: 56	20	9	111	85
12:01	19.8	10	110.5	84.5
:06	19.5	9.5	110	84
:11	20	10	110	85
: 16	19	10	111	85
:21	20	10	111	84
:26	20	10	111	84.5
:31	20	10	110.8	84.5
:36	20	10.5	111.5	85
:41	20	9	110	83.5
:46	20	10	111.1	85.5
:51	20	10	110.8	84.5
:56	19.2	12	114	89
1:01	20	9	111.5	86
:06	20	10	112	87
:11	20	10	113	88
:16	20	11	113.5	89
: 21	20	11	113.5	89
:26	20	11	113.5	89
:31	19.8	10	113.2	89
:				
Average Values	19.95	10	111.6	85

Water evaporated - 123.4 lbs.
Initial temperature - 61° F.

Steam condensed - 177 lbs.

Barometer - 29.55 inches.

Quality of steam -
Weight of steam - .21 lbs.
Weight of water - .038 lbs.

Run One.

Vacuum, corrected-	19.7 inches.
Absolute pressure -	4.7 lbs.

# #

Temperatures in degrees F.

Inlet	231.4
Exhaust	185
Boil. point of water(4.7 lbs)	159.5

# #

Latent heats -

At 231.4°F.	958.0 B.T.U.
At 4.7 lbs.	1002.0 B.T.U.

# #

Quality of steam, corrected -

$$x = \frac{.21}{.248} = .85 \qquad 85\ \%$$

$$X_c = \frac{.85x897+286-206}{958} = .875 \quad 87.5\ \%$$

# #

Heat lost by steam -

177(.875x958+231.4-185) =156,200 B.T.U.

Heat transferred to water -

123.4[1002+(159.5-60)] = 135,700 B.T.U.

Efficiency ofevaporation - 86.8 %.

# #

Capacity of evaporation -

$$C = \frac{123.4}{10x177x886.8} = .00075 \text{ lbs.}$$

# #

Velocity of steam thru tubes -

Specific volume at 208°F. -	28.75 cu.ft.
Density -	.0347 lbs

$$V= \frac{177x28.75x.875}{.0694x120} = 536 \text{ ft./min.}$$

# #

Coefficient of heat transference -

$$d' = 231.4 - \frac{159.5+60}{2} = 121^{0}\ F.$$

$$K = \frac{135,700x60}{2x10.8x121.4x536x.0347} = 167.$$

Run Two.

Time	Vacuum	Steam Pressure	Temperature of Steam	
			Inlet	Exhaust
7:15	17	15	119° C.	97° C.
:20	18.2	9	106.5	85
:25	18	10	107	84.5
:30	18	10	109	84.5
:35	18	11	110	85.5
:40	18	10	109	85
:45	18	10	109	85
:50	18	10	107	82.5
:55	18	10	107.5	85.5
8:00	18	10	110	83.5
:05	18	10	112	86.5
:10	17	10	112	86
:15	18	10	112	85
:20	18	10	113	85
:25	18	9	110.5	84.5
:30	18	10	112.2	86
:35	18	10	113	86
:40	18	10	112	85
:45	18	10	110.2	86
:50	18	10	113	85
:55	18	10	112	84
9:00	18	10	114	86
:05	18	10	113.1	84
:10	18	10	115.1	85
:15	18	10	113	84
Average Values	18	10	111.2	85.5

Water evaporated - 72.4 lbs.
Initial temperature - 60° F.

Steam condensed - 103.6 lbs.

Barometer - 29.55

Quality of steam -
Weight of water - .038 lbs.
Weight of steam - .21 lbs.

Run Two.

Vacuum, corrected - 17.7 inches.
Absolute pressure - 5.86 lbs.

#   #

Temperature in degrees F.
Inlet - 230.5
Exhaust - 186
Boiling point at 5.86 lbs. - 168.5

#   #   #

Latent heats -
At 230.5° F. - 959.0 B.T.U.
At 5.86 lbs. - 997.0 B.T.U.

#   #

Quality of steam, corrected -

$$x = \frac{.21}{.248} = .85 \qquad 85\ \%$$

$$Xc = \frac{.85x897+286-206}{959} = .875 \qquad 87.5\ \%$$

#   #

Heat lost by steam -

$$103.6(.875x959+44.5) = 91,800 \text{ B.T.U.}$$

Heat transferred to water -

$$72.4[997+(168.5-60)] = 80,000 \text{ B.T.U.}$$

Efficiency of evaporation - 87.2 %

#   #

Capacity of evaporation -

$$C = \frac{72.4}{10.8x103.6x895} = .00073 \text{ lbs.}$$

#   #

Velocity of steam thru tubes -
Specific volume at 208° F. 28.75 cu.ft.
Density - .0347 lbs.

$$V = \frac{103.6x28.75x.875}{.0694x120} = \qquad 314 \text{ ft./min.}$$

#   #

Coefficient of heat transference -

$$d' = 230.5 - \frac{168.5+60}{2} = \qquad 116.2$$

$$K = \frac{80,000x60}{2x10.8x116x314x.0347} = \qquad 175.$$

Run Three.

Time	Vacuum	Steam Pressure	Temperature of Steam Inlet	Exhaust
10:14	14.5	8	110 o C.	99o C.
:19	18	10	114	96
:24	18	10	114.5	86
:29	18	10	115	86.4
:34	18	10	114.3	85.5
:39	18	10	114.5	85.5
:44	18	10	114.8	85.5
:49	18	10	115	85.5
:54	18	10	115	86
:59	18	10	115.3	86
11:04	18	10	115	86
:09	18	10	115	86
:14	18	10	115.5	85.5
:19	18	10	115.	85.5
:24	18	10	115.5	85
:29	18	10	115	84.5
:34	18	10	114	83.2
:39	18	10	115.7	84.5
:44	18	10	115.5	84
:49	18	10	116	84
:54	18	10	115	83.2
:59	18	10	115.7	83
12:04	18	10	116	83.2
:09	18	10	116	83
:14	18	10	114.5	83
Average Values	18	10	115	86

Water evaporated -	100.1 lbs.
Initial temperature -	68.5° F.
Steam condensed -	136 lbs.
Barometer -	29.54
Quality of steam -	
Weight of steam -	1.1
Weight of water -	.151

Run Three.

Vacuum, corrected - 17.7 inches.
Absolute pressure - 5.86 lbs.

# #

Temperature in degrees F.-
Inlet - 250.2.
Exhaust - 186.8
Boiling point at 5.86 lbs.- 168.5

# #

Latent heats -
At 250.2°F. 945 B.T.U.
At 5.86 lbs. 997 B.T.U.

# #

Quality of steam, corrected -

$$x= \frac{1.1}{1.251} =.88 \qquad 88\ \%$$

$$X_c = \frac{.88x894.5+289.5-218.5x100}{945} = 90.5\ \%$$

# #

Heat lost by steam -

$$136(.905x945+250.2-63) = 124,800 \text{ B.T.U.}$$

Heat transferred to water -

$$100.1[997+168.5-68.5)] = 110,000 \text{ B.T.U.}$$

Efficiency of evaporation - 88.5 %

# #

Capacity of evaporation -

$$C = \frac{100.1}{10.8x124.800} = .000744 \text{ lbs.}$$

# #

Velocity if steam thru tubes -
Specific volume at 218.5°F.- 24 cu.ft.
Density - .01467 lbs.

$$V = \frac{.905x136x24}{.0694x120} = 355 \text{ ft./min.}$$

# #

Coefficient of heat transference -

$$d' =250.2-\frac{168.5+68.5}{2} = 132^{\circ} \text{ F.}$$

$$K = \frac{110,000x60}{2x10.8x132x355x.04167} = 156.$$

Run Four.

Time	Vacuum	Steam Pressure	Temperature of Steam Inlet	Temperature of Steam Exhaust
12:38	16	10	116.4° C.	78° C.
:43	20	10	114	80
:48	20	10	114	79.5
:53	20	10	115.4	79.5
:58	20	10	114.5	80.1
1:03	20	10	114	79.6
:08	20	10	114	79.5
:13	20	10	115	79.6
:18	20	10	114	79.5
:23	20	10	114.1	79.5
:28	20	10	113.4	79
:33	20	10	112	79
:38	20	10	110	78
:43	20	10	111	78
:48	20	10	111	78.6
:53	20	10	111.4	78.6
:58	18.5	10	110.5	79.5
2:03	20	10	110.5	78.5
:08	20	10	111	78.2
:13	20	10	110	77.5
:18	20	20	111	78
:23	20	10	111	78.2
:28	20	10	111	78.2
:33	20	10	111	78
:38	20	10	110	78
Average Values	20	10	112.5	78.7

Water evaporated - 100.6 lbs.
Initial temperature - 63° F.

Steam condensed - 140 lbs.

Barometer - 29.54 inches.

Quality of steam - 1.1 lbs.
Weight of steam -
Weight of water - .151 lbs.

Run Four.

Vacuum, corrected - 19.7 inches.
Absolute pressure - 4.85 lbs.

# #

Temperatures in degrees F.
Inlet - 233.5
Exhaust - 173.8
Boiling point at 4.85 lbs.- 160.1

# #

Latent heats -
At 233.5°F.- 956 B.T.U.
At 4.85 lbs.- 1002 B.T.U.

# #

Quality of steam, corrected -

$$x = \frac{1.1}{1.251} = .88 \qquad 88\ \%$$

$$X_c = \frac{.88x\ 894.5+289.5-202}{956} = 91\ \%$$

# #

Heat lost by steam -

$140(.91x956+60) = 130,100$ B.T.U.

Heat transferred to water -

$100.6[1002+(160.1-63)] = 110,500$ B.T.U.

Efficiency of evaporation - 85 %

# #

Capacity of evaporation -

$$C = \frac{100.6}{10.8x130,100} = .000715 \text{ lbs.}$$

# #

Velocity of steam thru tubes -
Specific volume at 203.5° F. - 31.72 cu.ft.
Density - .03153 lbs.

$$V = \frac{140x31.72x.91}{.0694x120} = 485 \text{ ft./min.}$$

# #

Coefficient of heat transference -

$$d' = 233.5 - \frac{160.1+63}{2} = 164^\circ \text{ F.}$$

$$K = \frac{110,000x60}{2x10.8x122x485x.03153} = 164.$$

Data

and

Calculations

for the

Lead Tubes.

Run One.

Time	Vacuum	Steam Pressure	Temperature of Steam Inlet	Exhaust
1:59	20	10	113° C	95.5° C
2:04	20	10	112.5	84
:09	20	10	112	82
:14	20	10	111.5	81
:19	20	10	111.5	81
:24	20	10	112	81.5
:29	20	10	112	81
:34	20	10	112	80
:39	20	10	112	78.5
:44	20	10	112	78
:49	20	10	112.5	78.5
:54	20	10	112	78.5
:59	20	10	113	79
3:04	20	10	113	79
:09	20	10	113	79
:14	20	10	112	79
:19	20	10	112	79
:24	20	10	112,5	78
:29	20	10	113	78.5
:34	20	10	113	79
:39	20	10	113	79
:44	20	10	112	79
:49	20	10	113	80
:54	20	10	113	80
:59	20	10	113	80.5
Average Values	20	10	112.5	80.5

Water evaporated - 101.6 lbs.
Initial temperature - 78.5° F.

Steam condensed - 147.3 lbs.

Barometer - 29.5 inches.

Quality of steam -
Weight of water - .105 lbs.
Weight of steam - .63

Run One.

Vacuum, corrected -	19.7 inches.
Absolute pressure -	4.8 lbs.

#   \#

Temperatures in degrees F.-

Inlet -	234
Exhaust -	177
Boiling point at 4.8 lbs.-	160.3

#   \#

Latent heats -

At 234^{0} F.-	956 B.T.U.
At 4.8 lbs. -	1001.4 B.T.U.

#   \#

Quality of steam, corrected -

$$x = \frac{.63}{.735} = .86 \qquad 86\ \%$$

$$X_c = \frac{.86\times 894.1+290.2-202.1}{956} = 89.5\ \%$$

#   \#

Heat lost by steam -

147.3(.895x956+234-177) = 134,400 B.T.U.

Heat transferred to water -

101.6[1001.4+(160.3-78.5)] = 110,500 B.T.U.

Efficiency of evaporation - 82.5 %

#   \#

Capacity of evaporation -

$$C = \frac{101.6}{782\times 134,400} = .000965 \text{ lbs.}$$

#   \#

Velocity of steam thru tubes -

Specific volume at 205.5° F.-	29.92 cu.ft.
Density -	.0334 lbs.

$$V = \frac{147.3\times .895\times 29.92}{.0334\times 120} = 929.5 \text{ ft./min.}$$

#   \#

Coefficient of heat transference -

$$d' = 234 - \frac{160.3+78.5}{2} = 115.4^{0} \text{ F.}$$

$$K = \frac{110,500\times 60}{2\times 782\times 115.4\times 929.5\times .0334} = 118.6$$

Run Two.

Time	Vacuum	Steam Pressure	Temperature of Steam Inlet	Exhaust
6:32	18	10	113° C	102° C
:37	18	10	112.5	91.5
:42	18	10	113	86
:47	18	10	113	83
:52	18	10	112	82.5
:57	18	10	112	82
7:02	18	10	112	82
:07	18	10	111	82
:12	18	10	112	83
:17	18	10	112	83.5
:22	18	10	111	84.5
:27	18	10	112	83.5
:32	18	10	111.5	83.5
:37	18	10	112	84
:42	18	10	112	84
:47	18	10	111	83.5
:52	18	10	112	83.7
:57	18	10	112	84
8:02	18	10	111	84
:07	18	10	112	84
:12	18	10	112	84.5
:17	18	10	112	84.5
:22	18	10	112	84.5
:27	18	10	111	85.5
:32	18	10	112	85.5
Average Values	18	10	112	84

Water evaporated - 104.9 lbs.
Initial temperature - 71° F.

Steam condensed - 152.4 lbs.

Barometer - 29.5 inches.

Quality of steam -
Weight of steam - .63 lbs.
Weight of water - .105 lbs.

Run Two.

Vacuum, corrected - 17.7 inches.
Absolute pressure - 5.8 lbs.

# #

Temperatures in degrees F.
Inlet - 234
Exhaust - 183
Boiling point at 5.8 lbs. - 168.5

# #

Latent heats -
At 234° F.- 956 B.T.U.
At 5.8 lbs. - 997 B.T.U.

# #

Quality of steam, corrected -

$$x = \frac{.63}{.735} = .86 \qquad 86.\ \%$$

$$X_c = \frac{.86x894.1+290.2-202.1}{956} = 89.6\%$$

# #

Heat lost by steam -

$$152.4(.896x956+234-183) = 138,300\ B.T.U.$$

Heat transferred to water -

$$104.9[997+(168.5-71)] = 114,800\ B.T.U.$$

Efficiency of evaporation - 83 %

# #

Capacity of evaporation -

$$C = \frac{104.9}{7.82x138,300} = .00097\ lbs.$$

# #

Velocity of steam thru tubes-
Specific volume at 208.5° F.- 28.58 cu.ft.
Density - 03499 lbs.

$$V = \frac{152.4x28.58x.896}{.0354x120} = 919\ ft./min$$

# #

Coefficient of heat transference -

$$d' = 234 - \frac{168.5+71}{2} = 114^\circ\ F.$$

$$K = \frac{114,800x60}{2x7.82x114x919x.03499} = 120.$$

Run Three.

Time	Vacuum	Steam Pressure	Temperature of Steam	
			Inlet	Exhaust
12:11	20	10	111° C	83° C
:16	20	10	114	81.5
:21	20	10	113.5	81
:26	20	10	113	81.5
:31	20	10	113	81
:36	20	10	113.5	82
:41	20	10	113.5	80.5
:46	20	10	113	82
:51	20	10	113	84
:56	20	10	114	83
1:01	20	10	113.5	82.5
:06	20	10	113.5	82.5
:11	20	10	114	83
:16	20	10	113	82
:21	20	10	112	81
:26	20	10	113	82
:31	20	10	113	81.5
:36	20	10	113	82
:41	20	10	113	82
:46	17	10	113	84
:51	20	10	113	84.5
:56	20	10	113	83
2:01	20	10	113	81.5
:06	20	10	113	80.5
:11	20	10	113.5	81
Average Values	20	10	113.3	82.7

Water evaporated - 127.8 lbs.
Initial temperature - 72° F.

Steam condensed - 181.8 lbs.

Barometer - 29.4 inches.

Quality of steam -
Weight of steam - .53 lbs.
Weight of water - .079 lbs.

Run Three.

Vacuum, corrected - 19.7 inches.
Absolute pressure - 4.75 lbs.

#   #

Temperatures in degrees F.
Inlet - 236.2
Exhaust - 181
Boiling point at 4.75 lbs. - 160.

#   #

Latent heats -
At 236.2° F.- 954 B.T.U.
At 4.75 lbs .- 1001.6 B.T.U.

#   #

Quality of steam, corrected -

$$x = \frac{.53}{.609} = .87 \qquad 87\ \%$$

$$X_c = \frac{.87x891+294.2-205,2}{954} = .90 \qquad 90\ \%$$

#   #

Heat lost by steam -

181.8(.9x954+236.2-181) = 165,500 B.T.U.

Heat transferred to water -

127.8[1001.6+(160-72)] = 139,200 B.T.U.

Efficiency of evaporation - 84.2 %

#   #

Capacity of evaporation---

$$C = \frac{127.8}{7.82x165,500} = .00098 \text{ lbs.}$$

#   #

Velocity of steam thru tubes -
Specific volume at 208.5° F. 28.58 cu.ft.
Density - .03499 lbs

$$V = \frac{181.8x.90x28.58}{120x.0354} = 1098 \text{ ft./min.}$$

#   #

Coefficient of heat transference -

$$d' = 236.2 - \frac{160.+72}{2} = 120^{\circ} \text{ F.}$$

$$K = \frac{139,200x60}{2x7.82x120x1098x.03499} = 114.$$

Run Four.

Time	Vacuum	Steam Pressure	Temperature of Steam Inlet	Exhaust
10:00	18	10	113.5° C	103 °C
:05	18	10	114	96
:10	18	10	113	90.5
:15	18	10	112	89.5
:20	18	10	113.5	88
:25	18	10	113	86
:30	18	10	113	86
:35	18	10	113	86
:40	18	10	114	86.5
:45	18	10	113	86.5
:50	18	10	113	87
:55	18	10	112.5	87
11:00	18	10	113	88
:05	18	10	113	87
:10	18	10	113.5	88
:15	18	10	113.5	87.5
:20	18	10	113	88
:25	18	10	113	87.5
:30	18	10	113.5	87
:35	18	10	113	86.5
:40	18	10	113	87
:45	18	10	114	87
:50	18	10	114	87
:55	18	10	112.5	88
12:00	18	10	112.5	88
Average Value	18	10	113	87

Water evaporated - 117.6 lbs.
Initial temperature - 77.5° F.

Steam condensed - 172.75 lbs.

Barometer - 29.4 inches.

Quality of steam -
Weight of steam - .53 lbs.
Weight of water - .079 lbs.

Run Four.

Vacuum, corrected - 17.7 inches.
Absolute pressure - 5.75 lbs.

#   #

Temperature in degrees F.-
Inlet - 236
Exhaust - 188.5
Boiling point at 5.75 lbs.- 167.5

#   #

Latent heats-
At 236° F.- 954 B.T.U.
At 5.75 lbs. - 996.2 B.T.U.

#   #

Quality of steam, corrected -

$x = \frac{.53}{.609} = .86$ 86 %

$X_c = \frac{.86x891+294.2-205.2}{954} = .90$ 90 %

#   #

Heat lost by steam -

172.75(.9x954+236-188.5) = 156,500 B.T.U.

Heat transferred to water -

117.6[996.2+(167.5-77.5)] * 127,800 B.T.U.

Efficiency of evaporation - 82 %

#   #

Capacity of evaporation -

$C = \frac{117.6}{7.82x156,500} = .00096$ lbs.

#   #

Velocity of steam thru tubes -
Specific volume at 211° F. 26.79 cu.ft.
Density - .03664 lbs

$V = \frac{172,75x.9x26.79}{.0354x120} =$ 979 ft./min.

#   #

Coefficient of heat transference -

$d' = 236 - \frac{167.5+77.5}{2} =$ 114° F.

$K = \frac{127,800x60}{2x7.82x114x979x.03664} =$ 119.5.

Data

and

Calculations

for the

Steel Tubes.

Run One.

Time	Vacuum	Steam Pressure	Temperature of Steam	
			Inlet	Exhaust
11:17	18	10	119° C.	100° C.
:22	18	10	112	88
:27	18	10	112	88.5
:32	18	10	111.5	88
:37	18	10	110.5	87
:42	18	10	111.5	88
:47	18	10	111	87.5
:52	18	10	111.5	87.5
:57	18	10	111	86
12:02	18	10	111.5	86
:07	18	10	112	86
:12	18	10	112	85.5
:17	18	10	112	86
:22	18	10	112.5	86
:27	18	10	113	86
:32	18	10	113	85
:37	18	10	112.5	85.5
:42	18	10	112	85.5
:47	18	10	111.5	85
:52	18	10	112.5	84.5
:57	18	10	112	84.5
1:02	18	10	112	85
:07	18	10	112	85
:12	18	10	112	85
:17	18	10	112	85
Average Values	18	10	112.2	86.6

Water evaporated - 118 lbs.
Initial temperature - 75° F.

Steam condensed - 173.25 lbs.

Barometer - 29.5 inches.

Quality of steam -
Weight of steam - .71 lbs.
Weight of water - .125 lbs.

Run One.

Vacuum, corrected - 17.7 inches.
Absolute pressure - 5.8 lbs.

# #

Temperature in degrees F.-
Inlet - 234
Exhaust - 187.8
Boiling point at 5.8 lbs.- 167.8

# #

Latent heats -
At 234° F. - 956 B.T.U.
At 5.8 lbs.- 996 B.T.U.

# #

Quality of steam, corrected -

$$x = \frac{.71}{.835} = .85 \qquad 85\ \%$$

$$X_c = \frac{.85x894.2+290.2-202.1}{956} = .885 \qquad 88.5\ \%$$

# #

Heat lost by steam -

173.25(.885x956+234-187.8) = 154,900 B.T.U.

Heat transferred to water -

118[996+(167.8-75)] = 129,100 B.T.U.

Efficiency of evaporation - 83.5 %

# #

Capacity of evaporation -

$$C = \frac{118}{8.56x154,900} = .00089 \text{ lbs.}$$

# #

Velocity of steam thru tubes -
Specific volume at 211° F. - 27.29 cu.ft.
Density - .03664 lbs

$$V = \frac{173.25x.885x27.29}{.0436x120} = 800 \text{ ft./min.}$$

# #

Coefficient of heat transference -

$$d' = 234 - \frac{167.8+75}{2} = 112^\circ \text{ F.}$$

$$K == \frac{129,100x60}{2x856x112x800x.0364} = 137.5.$$

Run Two.

Time	Vacuum	Steam Pressure	Temperature of Steam	
			Inlet	Exhaust
1:35	20	10	112° C.	81.5° C
:40	20	10	112	81
:45	20	10	112	80.5
:50	20	10	112.5	81
:55	20	10	111.5	81
2:00	20	10	112	81
:05	20	10	113	81.5
:10	20	20	113	83
:15	20	10	113	83
:20	20	10	112.5	82.5
:25	20	10	112	82.5
:30	20	10	112	82.5
:35	20	10	112	82.5
:40	20	10	113	83
:45	20	10	112	82.5
:50	20	10	111	81.5
:55	20	10	112	82
3:00	20	10	112	82.5
:05	20	10	112	82.5
:10	20	10	112.5	82.5
:15	20	10	112	82.5
:20	20	10	111.5	81
:25	20	10	111.5	80.5
:30	20	10	112	80.5
:35	20	10	112	80.5
Average Values	20	10	112	81.8

Water evaporated - 122.1 lbs.
Initial temperature - 71° F.

Steam condensed - 176.1 lbs.

Barometer - 29.5 inches

Quality of steam -
Weight of steam - .71 lbs.
Weight of water - .125 lbs.

Run Two.

Vacuum, corrected - 19.7 inches.
Absolute pressure - 4.83 lbs.

# #

Temperatures in degrees F.-
Inlet - 234
Exhaust - 179
Boiling point at 4.83 lbs.- 160.9

# #

Latent heats -
At 234° F. - 956.2 B.T.U.
At 4.83 lbs.- 1001.5 B.T.U.

# #

Quality of steam, corrected -

$$x = \frac{.71}{.835} = .85 \qquad 85\ \%$$

$$X_c = \frac{.85 \times 894.2 + 290.2 - 202}{956} = .885 \qquad 88.5\ \%$$

# #

Heat lost by steam -

$$176.1(.885 \times 956.2 + 234 - 179) = 159{,}000 \text{ B.T.U.}$$

Heat transferred to water -

$$122.1[1001.5 + (160.9 - 71)] = 133{,}800 \text{ B.T.U.}$$

Efficiency of evaporation - 84 %

# #

Capacity of evaporation -

$$C = \frac{122.1}{8.56 \times 159{,}000} = .000897 \text{ lbs.}$$

# #

Velocity of steam thru tubes -
Specific volume at 206.5° F. 29.39 cu.ft.
Density - .03402 lbs

$$V = \frac{176.1 \times .885 \times 29.39}{.0436 \times 120} = 877 \text{ ft./min}$$

# #

Coefficient of heat transference -

$$d' = 234 - \frac{161+71}{2} = 118^\circ \text{ F.}$$

$$K = \frac{133{,}800 \times 60}{2 \times 8.56 \times 118 \times 877 \times .03402} = 133.$$

Run Three.

Time	Vacuum	Steam Pressure	Temperature of Steam	
			Inlet	Exhaust
9:57	20	10	112.5° C	89° C
10:02	20	10	110	87.5
:07	20	10	110	86.5
:12	20	10	110	85.5
:17	20	10	1093	85
:22	20	10	110	85.5
:27	20	10	109	86
:32	20	10	110	85.5
:37	20	10	109.5	85
:42	20	10	110	84
:47	20	10	109	84.4
:52	20	10	110	84.5
:57	20	10	110	84
11:02	20	10	111	83.5
:07	20	10	110	83
:12	20	10	110	84
:17	20	10	110	85
:22	20	10	111	85.5
:27	20	10	112	85
:32	20	10	112	85.5
:37	20	10	111	86
:42	20	10	115	86
:47	20	10	114.5	85
:52	20	10	113	85.5
:57	20	10	113	85
Average Values				
	20	10	111	85.2

Water evaporated -	110.6
Initial temperature -	67.5° C
Steam condensed -	165.05 lbs.
Barometer -	29.6 inches.
Quality of steam -	
Weight of steam -	.43 lbs.
Weight of water -	.075 lbs.

Run Three.

Vacuum, corrected - 19.7 inches.
Absolute pressure - 4.87 lbs.

# #

Temperatures in degrees F.-
Inlet - 231.8
Exhaust - 185.2
Boiling point at 4.87 lbs.- 161.2

# #

Latent heats -
At 231.8° F.- 958 B.T.U.
At 4.87 lbs. - 1001 B.T.U.

# #

Quality of steam, corrected -

$$x = \frac{.43}{.505} = .85 \qquad 85\ \%$$

$$Xc = \frac{.85x897.1+286-199.1}{958} = .888 \qquad 88.8\ \%$$

# #

Heat lost by steam -

$$165.05(958x.888+231.8-185.2) = 148,500 \text{ B.T.U.}$$

Heat transferred to water -

$$110.6[1001+(161.2-67.5)] = 121,000 \text{ B.T.U.}$$

Efficiency of evaporation - 81.6 %

# #

Capacity of evaporation -

$$C = \frac{110.6}{8.56x148,500} = .00088 \text{ lbs.}$$

# #

Velocity of steam thru tubes-
Specific volume at 208.5° F.- 28.85 cu.ft.
Density - .03466 lbs

$$V = \frac{165.05x.888x28.85}{.0436x120} = 808 \text{ ft./min.}$$

# #

Coefficient of heat transference -

$$d' = 232 - \frac{161.2+67.5}{2} = 118\ ^{\circ}\text{F.}$$

$$K = \frac{121,000x60}{2x8.56x118x808x.03466} = 128.$$

Run Four.

Time	Vacuum	Steam Pressure	Temperature of Steam Inlet	Exhaust
10:44	18	10	114° C	88.5° C
:49	18	10	110.5	88
:54	18	10	111	88
:59	18	10	111	88
11:04	18	10	111	88
:09	18	10	111	88
:14	18	10	111	88
:19	18	10	110.5	87
:24	18	10	111	87
:29	18	10	111	87.5
:34	18	10	110.5	86
:39	18	10	111.5	87
:44	18	10	112	86.5
:49	18	10	110.5	85.5
:54	18	10	110.5	86
:59	18	10	110.5	86
12:04	18	10	110.5	86
:09	18	10	111	85.5
:14	18	10	111	85.5
:19	18	10	111	85
:24	16	10	112	88
:29	14	10	112	88
:34	14	10	112	87.5
:39	16	10	112	85.5
:44	18	10	112	84.5
Average Values	17.5	10	111.2	86.8

Water evaporated - 113.5 lbs.
Initial temperature - 72° F.

Steam condensed - 175.14 lbs.

Barometer - 29.3 inches.

Quality of Steam -
Weight of steam - 1.35 lbs.
Weight of water - .24 lbs.

Run Four.

Vacuum, corrected - 17.2 inches.
Absolute pressure - 5.95 lbs.

# #

Temperatures in degrees F. -
Inlet - 232.
Exhaust - 188.2
Boiling point at 5.95 lbs. - 170

# #

Latent heats -
At 232° F. - 959 B.T.U
At 5.95 lbs. - 995 B.T.U.

# #

Quality of steam, corrected -

$$x = \frac{1.35}{1.59} = .85 \qquad 85\ \%$$

$$X_c = \frac{.85x900+281.3-200.8}{959} = \qquad 88.5\ \%$$

# #

Heat lost by steam -

$$175.14(.885x959+232-188.2) = 155,000\text{B.T.U.}$$

Heat transferred to water -

$$113.5[996+(170-72)] = 124.500\text{ B.T.U.}$$

Efficiency of evaporation - 81 %

# #

Capacity of evaporation -

$$C = \frac{113.5}{8.56x155,000} = .000855\text{lbs.}$$

# #

Velocity of steam thru tubes -
Specific volume at 210° F. - 27.8 cu.ft.
Density - .036 lbs.

$$V = \frac{175.14x.885x27.8}{.0436x120} = \qquad 812\text{ ft./min.}$$

# #

Coefficient of heat transference -

$$d' = 232-\frac{170+72}{2} = \qquad 111^\circ\text{ F.}$$

$$K = \frac{124,500x60}{2x8.56x111x812x.036} = 134.$$

Data

and

Calculations

for the

Tin Tubes.

Run One.

Time	Vacuum	Steam Pressure	Temperature of Steam Inlet	Exhaust
11:37	19	10	113.5° C	74.5° C
:42	20	10	114	71
:47	20	10	114	69.5
:52	20	10	114	70
:57	20	10	113	70
12:02	20	10	114.5	70.5
:07	20	10	115	70
:12	20	10	113.5	70.5
:17	20	10	113.5	70.5
:22	20	10	113.5	70.5
:27	20	10	114	70.5
:32	20	10	113	70
:37	20	10	113.5	70.5
:42	20	10	113.5	70
:47	20	10	113	70
:52	20	10	113.5	70
:57	20	10	115.5	70.5
1:02	20	10	113	70.5
:07	20	10	113	70.5
:12	20	10	113	70
:17	20	10	113	70
:22	20	10	113	70.5
:27	20	10	113	70.5
:32	20	10	112	70
:37	20	10	112	70
Average Values	20	10	113.5	71

Water evaporated - 121.4 lbs.
Initial temperature - 68° F.

Steam condensed - 174.4 lbs.

Barometer - 29.96 inches.

Quality of steam -
Weight of steam - .4 lbs.
Weight of water - .068 lbs.

Run One.

Vacuum, corrected - 19.7 inches.
Absolute pressure - 4.9 lbs.

#   #

Temperatures in degrees F.
Inlet - 238
Exhaust - 160
Boiling point at 4.9 lbs.- 161.5

#   #

Latent heats -
At 238° F.- 954 B.T.U.
At 4.9 lbs.- 1001 B.T.U.

#   #

Quality of steam, corrected -

$$x = \frac{.4}{.468} = .86 \qquad 86\ \%$$

$$X_c = \frac{.86x891.2+291.7-207}{954} = .89 \qquad 89\ \%$$

#   #

Heat lost by steam -

$$174.4(.89x954+238-160) = 162,000 \text{ B.T.U.}$$

Heat transferred to water -

$$121.4[1001+(161.5-68)] = 131,500 \text{ B.T.U.}$$

Efficiency of evaporation - 81.5 %

#   #

Capacity of evaporation -

$$C = \frac{121.4}{8.22x162,000} = .000913 \text{ lbs.}$$

#   #

Velocity of steam thru tubes -
Specific volume at 199° F.- 34.26 cu.ft.
Density - .02919 lbs.

$$V = \frac{.89x174.4x34.26}{.0402x120} = 1110 \text{ ft./min.}$$

#   #

Coefficient of heat tranference -

$$d' = 238 - \frac{161.5+68}{2} = 123° \text{ F.}$$

$$K = \frac{131,\overset{5}{0}00x60}{2x8.22x123x1110x.02919} = 121.$$

Run Two.

Time	Vacuum	Steam Pressure	Temperature of Steam	
			Inlet	Exhaust
2:06	18	10	113° C	76° C
:11	18	10	113	73
:16	18	10	115.5	74
:21	18	10	114	74.5
:26	18	10	114	74.5
:31	18	10	113	74
:36	18	10	113.5	74.5
:41	18	10	113	75
:46	18	10	114	75
:51	18	10	113.5	74.5
:56	18	10	113.5	74.5
3:01	19	10	113	74
:06	18	10	113	74.5
:11	18	10	114	75
:16	18	10	113	74.5
:21	18	10	113	75
:26	18	10	114	74.5
:31	18	10	114	74.5
:36	18	10	114	74.5
:41	18	10	114	74.5
:46	18	10	113.5	74.5
:51	18	10	114	74
:56	18	10	114	73
4:01	18	10	113	72.5
06	18	10	112	72
Average Values	18	10	113	74

Water evaporated - 104.2 lbs.
Initial temperature - 63° F.

Steam condensed - 155.5 lbs.

Barometer - 29.96

Quality of steam -
Weight of steam - .4 lbs.
Weight of water - .068 lbs.

Run Two.

Vacuum, corrected - 17.7 inches.
Absolute pressure - 5.96 lbs.

# #

Temperatures in degrees F.
Inlet - 236
Exhaust - 165.1
Boiling point at 5.96 lbs. - 168.5

# #

Latent heats -
At 236° F. - 955 B.T.U.
At 5.96 lbs. - 997 B.T.U.

# #

Quality of steam, corrected -

$$x = \frac{.40}{.468} = .86 \qquad 86\ \%$$

$$X_c = \frac{.86 \times 891 + 291.7 - 207}{955} = .89 \qquad 89\ \%$$

# #

Heat lost by steam -

$$155.5(.86 \times 955 + 236 - 165.1) = 143,400 \text{ B.T.U.}$$

Heat transferred to water -

$$104.2[997 + (168.5 - 63)] = 115,000 \text{ B.T.U.}$$

Efficiency Of evaporation - 80.5 %

# #

Capacity of evaporation -

$$C = \frac{104.2}{8.22 \times 143,400} = .00089 \text{ lbs.}$$

# #

Velocity of steam thru tubes -
Specific volume at 202.5°F.- 33.31 cu.ft.
Density - .0301 lbs.

$$V = \frac{.89 \times 155.5 \times 33.31}{.0402 \times 120} = 955 \text{ ft./min.}$$

# #

Coefficient of heat transference -

$$d' = 236 - \frac{168.5 + 63}{2} = 120^\circ \text{ F.}$$

$$K = \frac{115,000 \times 60}{2 \times 8.22 \times 120 \times 955 \times .0301} = 122.$$

Run Three

Time	Vacuum	Steam Pressure	Temperature of Steam Inlet	Exhaust
11:18	18	10	113° C	104° C
:23	18	10	115	89
:28	18	10	113	82.5
:33	18	10	114	86
:38	18	10	114	85
:43	18	10	114	84
:48	18	10	114	83.5
:53	18	10	114	82
:58	18	10	114	82
12:03	18	10	115.5	83
:08	18	10	114.5	83
:13	18	10	114	82
:18	18	10	114.5	81
:23	18	10	115	81
:28	18	10	115	80.5
:33	18	10	114	77.5
:38	18	10	114	78
:43	18	10	114.	78
:48	18	10	114	79.5
:53	18	10	114	78
:58	18	10	111.5	78
1:03	18	10	114	79
:08	18	10	114	78.5
:13	18	10	114	78.5
:18	18	10	113.5	77.5
Average Values	18	10	114	82

Water evaporated - 153.4 lbs.
Initial temperature - 68° F.

Steam condensed - 224.81 lbs.

Barometer - 29.45 inches.

Quality of steam -
Weight of steam - .37 lbs.
Weight of water - .06 lbs.

Run Three.

Vacuum, corrected - 17.7 inches.
Absolute pressure - 5.85 lbs.

# #

Temperatures in degrees F.
Inlet - 237.5
Exhaust - 179
Boiling point at 5.85 lbs. - 168.5

# #

Latent heats -
At 237.5° F. 954 B.T.U.
At 5.85 lbs. 996 B.T.U.

# #

Quality of steam, corrected -

$$x = \frac{.37}{.43} = .86 \qquad 86\,\%$$

$$X_c = \frac{.86\times891+291.7-207}{954} = .89 \qquad 89\,\%$$

# #

Heat lost by steam -

$224.81(.89\times954+58.5) =$ 204,000 B.T.U.

Heat transferred to water -

$153.4[(996+168.5-68)] =$ 168,000 B.T.U.

Efficiency of evaporation - 82 %

# #

Capacity of evaporation -

$$C = \frac{153.4}{8.22\times204,000} = .000915 \text{ lbs.}$$

# #

Velocity of steam thru tubes -
Specific volume at 208.2° F. 28.41 cu.ft
Density - .0352 lbs

$$V = \frac{.89\times224.8\times28.41}{.0402\times120} = \qquad 1180 \text{ ft./min}$$

# #

Coefficient of heat transference -

$$d' = 237.5 - \frac{168.5+68}{2} = \qquad 119^\circ \text{ F.}$$

$$K = \frac{168,000\times60}{2\times8.22\times119\times1180\times.0352} = \qquad 123.5.$$

Run Four

Time	Vacuum	Steam Pressure	Temperature of Steam	
			Inlet	Exhaust
9:40	20	10	113.5° C	82 ° C
:45	20	10	115	77
:50	20	10	113	75
:55	20	10	113	75
10:00	20	10	113	74.5
:05	20	10	113	74
:10	20	10	113	74
:15	20	10	113	74
:20	20	10	113	73.5
:25	20	10	115	73.5
:30	20	10	113	73
:35	20	10	116.5	72
:40	20	10	113	72
:45	20	10	112	72
:50	20	10	113	73.5
:55	20	10	112	74
11:00	20	10	112	72.5
:05	20	10	113	74
:10	20	10	112.5	74
:15	20	10	112.5	72.5
:20	20	10	112	72
:25	20	10	112	73
:30	20	10	112.5	72
:35	20	10	112	72
:40	20	10	112	715
Average Values	20	10	112.7	73.5

Water evaporated - 126.8 lbs.
Initial temperature - 75° F.

Steam condensed - 185.4 lbs.

Barometer - 29.4 inches.

Quality of steam -
Weight of steam - .36 lbs.
Weight of water - .059 lbs.

Run Four.

Vacuum, corrected - 19.7 inches.
Absolute pressure - 4.65 lbs.

# #

Temperature in degrees F.
Inlet - 235
Exhaust - 164
Boiling point at 4.65 lbs. 160.1

# #

Latent heats -
At 235° F. - 956 B.T.U.
At 4.65 lbs. - 1002.5B.T.U.

# #

Quality of steam corrected -

$$x = \frac{.36}{.419} = .86 \qquad 86\ \%$$

$$X_c = \frac{.86 \times 891 + 292.7 - 207}{956} = .89 \qquad 89\ \%$$

# #

Heat lost by steam -

$$185.4(.89 \times 956 + 235 - 164) = 170{,}700 \text{ B.T.U.}$$

Heat transferred to water -

$$125.8[1002.5 + (160.1 - 75)] = 138.700 \text{ B.T.U.}$$

Efficiency of evaporation - 81.5 %

# #

Capacity of evaporation -

$$C = \frac{126.8}{8.22 \times 170{,}700} = .000905 \text{ lbs.}$$

# #

Velocity of steam thru tubes -
Specific volume at 199.5° F. 33.72 cu.ft.
Density - .02942 lbs.

$$V = \frac{.89 \times 185.4 \times 33.72}{.0402 \times 120} = 1150 \text{ ft./min.}$$

# #

Coefficient of heat transference -

$$d' = 235 - \frac{160+75}{2} = 117.5^\circ\text{F.}$$

$$K = \frac{138{,}700 \times 60}{2 \times 8.22 \times 117.5 \times 1150 \times .02942} = 124.$$

Data

and

Calculations

for the

Aluminum Tubes.

Run One.

Time	Vacuum	Steam Pressure	Temperature of steam	
			Inlet	Exhaust
12:00	18	10	111° C	95 ° C
:05	18	10	109	86
:10	18	10	108.5	85
:15	18	10	109.5	85
:20	18	10	110	86
:25	18	10	110	86
:30	18	10	110	85
:35	18	10	111	85
:40	18	10	111	84.5
:45	18	10	111.5	85
:50	18	10	112	85
:55	18	10	112	85
1:00	18	10	112	85
:05	18	10	111.5	85
:10	18	10	111	85
:15	18	10	111.5	84.5
:20	18	10	111.5	84
:25	18	10	111.5	83.5
:30	18	10	111	83
:35	18	10	111	83
:40	18	10	111	83
:45	18	10	111	82.5
:50	18	10	111	82
:55	18	10	111.5	83
2:00	18	10	111	81.5
Average Values	18	10	111	84.4

Water evaporated - 120 lbs.
Initial temperature - 75° F.

Steam condensed - 182 lbs.

Barometer - 29.6 inches.

Quality of steam -
Weight of steam - .55 lbs.
Weight of water - .105 lbs.

Run One.

Vacuum, corrected - 17.7 inches.
Absolute pressure - 5.84 lbs.

#   #

Temperatures in degrees F.-
Inlet - 232
Exhaust - 184
Boiling point at 5.84 lbs.- 168.3

#   #

Latent heats -
At 232° F.- 958 B.T.U.
At 5.84 lbs.- 996 B.T.U.

#   #

Quality of steam, corrected -

$$x = \frac{.55}{.655} = .84 \qquad 84\ \%$$

$$X_c = \frac{.84x898+285-199.2}{958} = \qquad 88\ \%$$

#   #

Heat lost by steam -

182(.88x958+232-184) = 162,500 B.T.U.

Heat transferred to water -

120[996+(168.3-75)] = 130,000 B.T.U.

Efficiency of evaporation - 80 %

#   #

Capacity of evaporation -

$$C = \frac{120}{10.26x162,500} = .00072\ \text{lbs.}$$

#   #

Velocity of steam thru tubes -
Specific volume at 208° F.- 28.85 cu.ft.
Density - .03466 lbs

$$V = \frac{182x.88x28.85}{.063x120} = \qquad 612\ \text{ft./min.}$$

#   #

Coefficient of heat transmission -

$$d' = 232 - \frac{168.3+75}{2} = \qquad 110°\ F.$$

$$K = \frac{130,000x60}{2x10.26x110x612x.03476} = \qquad 163.$$

Run Two.

Time	Vacuum	Steam Pressure	Temperature of Steam	
			Inlet	Exhaust
2:11	18	10	107° C	87° C
:16	18	10	107	82.5
:21	18	10	107	82.5
:26	18	10	107	82
:31	18	10	108	82.5
:36	18	10	108	82.5
:41	18	10	108	83
:46	18	10	108	83
:51	18	10	107	81.5
:56	18	10	107	82
3:01	18	10	107.5	83
:06	18	10	108	82.5
:11	18	10	107	82
:16	18	10	108	83
:21	18	10	107.5	83
:26	18	10	107	82.5
:31	18	10	107	83
:36	18	10	107	83.5
:41	18	10	107	84
:46	18	10	107	83
:51	18	10	107.5	83.5
:56	18	10	107	83.5
4:01	18	10	106.5	83.5
:06	18	10	106	82.5
:11	18	10	107	83.5
Average values	18	10	107.5	82.8

Water evaporated - 113.7
Initial temperature - 73° F.

Steam condensed - 176.2 lbs.

Barometer - 29.6 inches.

Quality of steam -
Weight of steam - .55 lbs.
Weight of water - .105 lbs.

Run Two.

Vacuum, corrected - 17.7 inches.
Absolute pressure - 5.85 lbs.

# #

Temperatures in degrees F.-
Inlet - 226
Exhaust - 189
Boiling point at5.85 lbs. 168.3

# #

Laten~~d~~t heats-
At 226° F.- 962.1 B.T.U.
At 5.85 lbs. - 996 B.T.U.

# #

Quality of steam, corrected -

$$x = \frac{.55}{.655} = .84 \qquad .84\%$$

$$X_c = \frac{.84x898+285-199.1}{962.1} = .88 \qquad 88\ \%$$

# #

Heat lost by steam -

$$176.2(.88x962.1+226-189) = 155,500\ B.T.U.$$

Heat transferred to water -

$$113.7[996+(168.3-73)] = 124,100\ B.T.U.$$

Efficiency of evaporation - 80 %

# #

Cpacity of evaporation -

$$C = \frac{113.7}{10.26x155,500} = .000712\ lbs.$$

# #

Velocity of steam thru tubes -
Specific volume at 207.5° F. 29.64 cu.ft.
Density - .03435 lbs

$$V = \frac{176.2x.88x29.64}{.063x120} = 610\ ft./min.$$

# #

Coefficient of heat transference -

$$d' = 232 - \frac{168.3+73}{2} = 111^{0}\ F.$$

$$K = \frac{124,100x60}{2x10.26x111x610x.03435} =157.$$

Run Three.

Time	Vacuum	Steam Pressure	Temperature of Steam	
			Inlet	Exhaust
4:28	20	10	106° C	85° C
:33	20	10	106	82.5
:38	20	10	106	80.5
:43	20	10	105	80
:48	20	10	105	80
:53	20	10	104	79.5
:58	20	10	104.5	78.5
5:03	20	10	105.79	79
:08	20	10	104	78.5
:13	20	10	105	78
:18	20	10	105	80
:23	20	10	105	79.5
:28	20	10	105	79.5
:33	20	10	105.80	80
:38	20	10	105	80
:43	20	10	105	79.5
:48	20	10	104.5	80
:53	20	10	105	80
:58	20	10	105	81
6:03	20	10	105	61
:08	20	10	105	81
:13	20	10	105	81
:18	20	10	105	81
:23	20	10	105	81
:28	20	10	105	81
Average Values				
	20	10	105.1	80.5

Water evaporated -	118.6 lbs.
Initial temperature -	71° F.
Steam condensed -	173.2 lbs.
Barometer -	29.26 inches.
Quality of steam -	
Weight of steam -	.55 lbs.
Weight of water -	.105 lbs.

Run Three.

Vacuum, corrected - 19.7 inches.
Absolute pressure - 4.85 lbs

# #

Temperature in degrees F.-
Inlet - 221.2
Exhaust - 177.5
Boiling point at 4.85 lbs. 160.1

# #

Latent heats -
At 221.2° F.- 965 B.T.U.
At 4.85 lbs. - 1001.6B.T.U.

# #

Quality of steam, corrected -

$$x = \frac{.55}{.655} = .84 \qquad 84\ \%$$

$$X_c = \frac{.84x898+285-188.5}{965} = 88\ \%$$

# #

Heat lost by steam -

$$173.2(.88x965+221.2-177.5) = 154,600\ \text{B.T.U.}$$

Heat transferred to water -

$$118.6[1001.6+(160.1-71)] = 130,000\ \text{B.T.U.}$$

Efficiency of evaporation - 84 %

# #

Capacity of evaporation -

$$C = \frac{118.6}{10.26x154,600} = .00075\ \text{lbs.}$$

# #

Velocity of steam thru tubes -
Specific volume at 199° F. - 33.60 cu.ft.
Density - .02976 lbs

$$V = \frac{.88x173.2x33.60}{.063x120} = 677\ \text{ft./min.}$$

# #

Coefficient of heat transference -

$$d' = 221.2 - \frac{160+71}{2} = 106°\ \text{F.}$$

$$K = \frac{130,000x60}{2x10.26x106x677x.02976} = 177.$$

Run Four.

Time	Vacuum	Steam Pressure	Temperature of Steam Inlet	Exhaust
6:40	20	10	106° C	85.5°C
:45	20	10	106	83
:50	20	10	106	84.5
:55	20	10	106	83
7:00	20	10	106	83
:05	20	10	106	82.5
:10	20	10	106	83
:15	20	10	106	83
:20	20	10	106	83
:25	20	10	106	83
:30	20	10	106	83
:35	20	10	106	82.5
:40	20	10	106	82,5
:45	20	10	106	82.5
:50	20	10	106.5	82.5
:55	20	10	106.5	82
8:00	20	10	106.5	83
:05	20	10	107	83.5
:10	20	10	106.5	82.5
:15	20	10	106	83
:20	20	10	106	82.5
:25	20	10	106	82
:30	20	10	105.5	81
:35	20	10	105.5	81.5
:40	20	10	106	81.5
Average Values	20	10	106	83

Water evaporated - 149.4 lbs.
Initial temperature - 65° F.

Steam condensed - 230.85 lbs.

Barometer - 29.6 inches.

Quality of steam -
Weight of steam - .46 lbs.
Weight of water - .083 lbs.

Run Four.

Vacuum, corrected - 19.7 inches.
Absolute pressure - 4.85 lbs.

#   #

Temperatures in degrees F.-
Inlet - 222.9
Exhaust - 181
Boiling point at 4.85 lbs.- 160.1

#   #

Latent heats -
At 222.9° F. 959 B.T.U.
At 4.85 lbs. - 1001.6 B.T.U.

#   #

Quality of steam, corrected -

$$x = \frac{.46}{.543} = .85 \qquad 85\ \%$$

$$X_c = \frac{.85\text{x}897.8+285.8-197}{959} = .89 \qquad 89\ \%$$

#   #

Heat lost by steam -

$$230.85(.89\text{x}959+222.9-181) = 206{,}400 \text{ B.T.U.}$$

Heat transferred to water -

$$149.4[1001.6+(160.1-65)] = 163{,}200 \text{ B.T.U.}$$

Efficiency Of evaporation - 79.8 %

#   #   #

Capacity of evaporation -

$$C = \frac{149.4}{10.26\text{x}206{,}400} = .000705 \text{ lbs.}$$

#   #

Velocity of steam thru tubes -
Specific volume at 202° F. 32.32 cu.ft
Density - .03093 lbs

$$V = \frac{230.85\text{x}.89\text{x}32.32}{.063\text{x}120} = 875 \text{ ft./min.}$$

#   #

Coefficient of heat transference -

$$d' = 223-\frac{160.1+65}{2} = \qquad 110^\circ \text{ F.}$$

$$K = \frac{163{,}700\text{x}60}{2\text{x}10.26\text{x}110\text{x}875\text{x}.03093} = 161.$$

Conclusion.

In conclusion, we wish to give a comparative report of our results. It is not possible to compare exactly the action of the different metals with regard to their heat conducting properties, since they do not occur in exactly the same conditions of purity and thickness. In all the calculations, the thicknesses of the tubes are neglected, due to the fact that they have slight effect for the small values given.

Table of Results.

Values of K.

Vacuum	Copper	Lead	Steel	Tin	Aluminum
18in.	165.5	120	135.7	122.5	160
20 in.	165.5	116.3	131.5	122.5	169
Values of efficiency..					
18 in.	87.8	82.5	82.2	81.3	80
20 in.	86.2	83.1	82.8	81.5	81.9
Values of capacity.					
18 in.	.000737	.000975	.000872	.000896	.00071
20 in.	.00072	.000972	.000888	.000908	.00073

The following table shows the relation between the velocity of the steam in the tubes to the water evaporated, in each test.

Copper tubes.

Velocity	536 ft.	314 ft.	355 ft.	485 ft.per min.
Water evap.	123.4	72.4	100.1	100.6 pounds

Lead tubes.

Velocity	929.5	919	1098	979
Water evap.	101.6	104.9	181.8	117.6

Steel tubes.

Velocity	800	877	808	812
Water evap.	119	122.1	110.6	113.5

Tin tubes.

Velocity	1110	955	1180	1150
Water evap.	121.4	104.2	153.4	126.8

Alminum tubes.

Velocity	612	610	677	875
Water evap.	120	113.	118	149

With reference to the first three tables, the results for the different conditions of operation are shown to agree closely. The agreement is so general that we may state that variations in conditions of operation affect none of the constants of the metals, but serve merely to vary the capacity of the evaporator.

The capacities recorded in the tables represent the evaporation in pounds of water per square foot of heating surface per B. T. U. It remains practically constant. Values of the coefficient of heat transferrence and of efficiency are constant. The first three tables represent the averages of check runs, for the different conditions maintained during a run. The table of velocities shows the results for each run made on a tube.

In the following table , averages are reported. This is allowable, since it was found that no differences in the constants of the tubes were caused by the changes in the conditions.

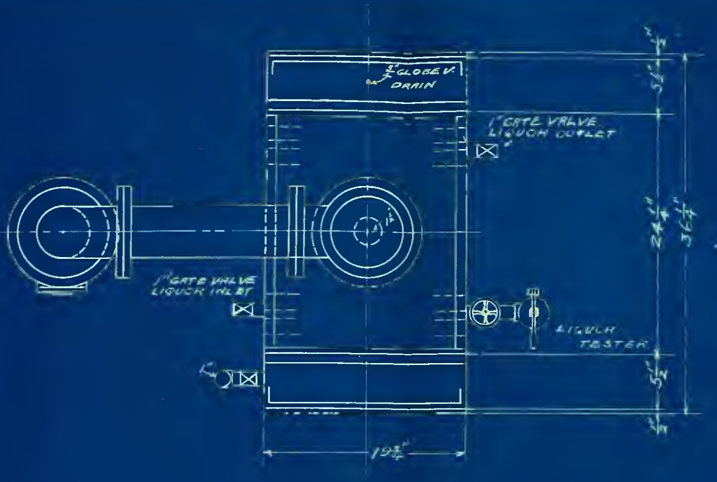
Table of Averages.

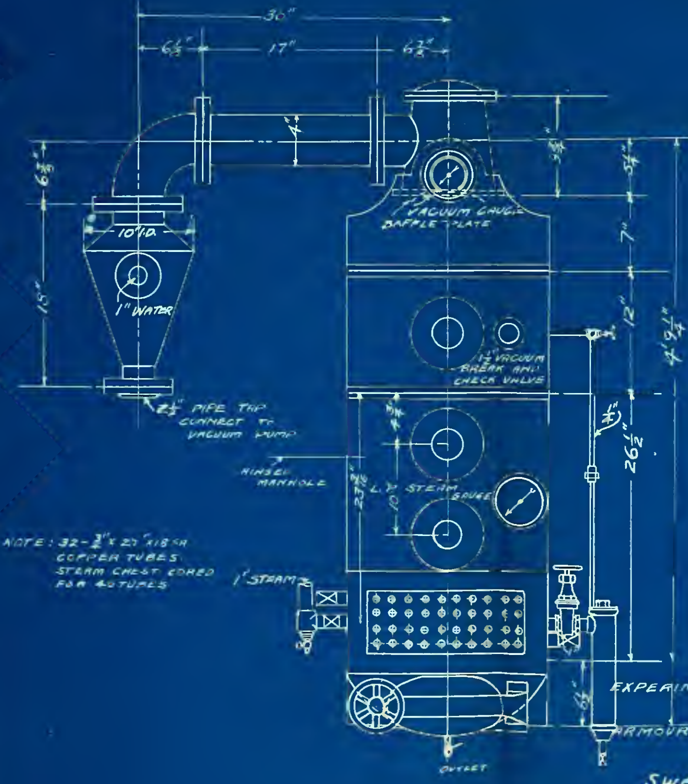
Metal	K	Efficiency	C
Copper	165.5	87 %	.000728
Lead	118.1	82.8 %	.000973
Steel	133.6	82.5 %	.00088
Tin	122.5	81.4 %	.000902
Aluminum	164.5	80.7 %	.00072

Copper, Lead, Steel, Tin, and Aluminum are the metals in order of their efficiencies. Copper stands prominently at the head of the list; the others run very closely, with a maximum variation of about two per cent.

From the standpoint of the industries, there is little choice between any of the tubes, with the exception of copper, on the basis of efficiency. The variation of the coefficient of heat transferrence of the different metals is shown in the table, likewise that of the capacity coefficient. The results obtained on the tin and lead tubes cannot be properly compared with the other results, for the reason that the temperature maintained during a test, caused an elongation of the tubes, with the resulting increase in heating surface which was impossible to measure accurately. This accounts for the unusual values of the constants of the lead and tin tubes, more so in the case of the former than in that of the latter.

The quality of the steam from the boiler was determined at boiler pressure. Steam was admitted to the evaporator at a pressure of ten pounds. The throttling of the steam through the valve dried it somewhat, necessitating the correction as made.





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